An Active Input Current Waveshaping with Zero Switching Losses for Three-Phase Circuit Using Power Diode

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***Abstract*—In this paper a zero voltage switched active network (Fig. 1) which can be used in conjunction with single-phase or three-phase ac to dc diode rectifiers is presented. It is shown that application of the proposed switching network in three-phase ac to dc boost converter yields zero switching losses while maintaining a unity input power factor. Active network capacitor, C_s, diodes D_7, and D_8, maintain a zero voltage during turn-off of Q_1, and Q_2, Capacitor, Cs, discharges through the boost inductors of the circuit thus limiting the rate of rise of current during turn-on. Moreover, the advantage of the proposed active network is that it can maintain a zero voltage switching over the entire range of the duty cycle of the operation. Consequently, boost stage can be used directly to control the dc bus voltage by varying the duty cycle at Constant switching frequency. The resulting advantages include higher switching frequencies, and better efficiency. Finally the operation of the active switching network is verified experimentally on a prototype three-phase ac to dc converter.**

I. Introduction

In recent years, conversion of ac line voltages from utilities has been dominated by using a single-phase diode rectifier followed by a single switch boost stage. Designers have embraced the usefulness of this topology since it draws a sinusoidal input current and maintains a unity input power factor under varying load condition. For medium to high power applications the input diode rectifier is fed from three-phase ac source. Application of the bang-bang hysteresis control method to improve the input power factor of a three-phase ac to dc converter has been discussed by several authors using three single-phase ac to dc converters with suitable input and output connections. This topology yields unity input power factor and is clearly much superior to the original phase controlled ac to dc topologies. However it also exhibits some disadvantages including;

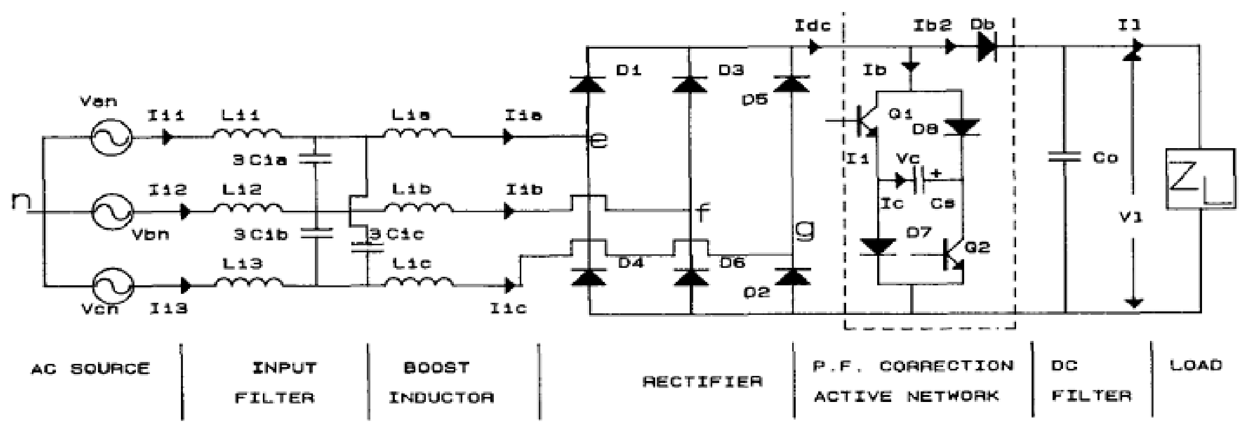

Figure 1. Three-phase ac -dc converter topology with the proposed active switching network

(i) It requires complicated input synchronization logic;
(ii) Owing to the variations in power circuit control Parameters among the three individual converters, a complete triplen harmonic elimination from the input line current (I_{ia}) cannot be achieved;
(iii) The switching frequency is load dependent;
(iv) The number of components required for three-phase ac to dc converter is three times the single-phase ac to dc converter;
(v) The advantages of using a three-phase inverter and transformer (better transformer core and copper utilization etc.) cannot be achieved.

All these disadvantages can be eliminated by using a three-phase ac to dc boost Converter topology Proposed in **[1]**and is shown in Fig.3**.**This topology not only operates at fixed switching frequency but also draws sinusoidal input Current

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from the ac Source at Unity input power factor and exhibits none Of the above mentioned disadvantages. However it has the disadvantages of substantially increasing the current stresses of the switching device ***(Q_b)*** and the high frequency ripple content of the pre-filtered ac input currents. To reduce the current stresses of the switching device, Fig. 3 is modified by replacing the boost switch **(Q_b)** with the proposed active switching network as shown in Fig.1.

The objective of this paper is to present an active switching network suitable for three-phase ac to dc boost converter (Fig. 1**)** so that the current stresses of the switching element can be reduced substantially. The resulting advantages include sinusoidal input current at unity power factor, higher switching frequencies and better efficiency. The principles of operation of the proposed converter are discussed in the next section.

II. Principles of Operation

A. Proposed Active Network

The proposed active switching network consists of a pair of series connected switch and diode and a capacitor ***(C_s)*** connected as shown in **fig. 1** Q_1 and Q_2 are turned 'on' and 'off 'simultaneously and the operation of the network is as follows. Considering the instant at time t_o when Q_1 and Q_2 are 'off' the current, $I_{b,}$ flowing through the active switching network is zero and the capacitor, C_s , is charged to V_l with a polarity shown in Fig. 1. During this period I_{dc} equal to I_{b2}. Turning-on Q_1 and Q_2 at t_1 (Fig. **4)** causes the capacitor C_s now charged at V_l to discharge through the boost inductors causing the current to flow through Q_1,C_s, and Q_2, thus limiting the rate of rise of current during turn-on. This operation continues until (t_2) the capacitor is discharged completely to zero. At the end of the discharge period (t_2) D_7 and D_8 start conduction and the current flowing through Q_1 flows through D_7 and the current flowing through D_8 flows through Q_2 i.e. The current flowing through Q_b in Fig. 3 is now being shared by the two parallel conducting paths and making the voltage across C_s zero. When the transistors (Q_1, and Q_2) are being turned-off at t_3 the current flowing through Q_1 and Q_2 now starts flowing through D_8, C_s, and D_7 thus causing the voltage across Q_1 and Q_2 zero during turn-off. Diodes $D_7$and D_8 cease conduction when the capacitor voltage becomes equal to V_l and diode D_b starts conduction at t_4. During the next cycle similar condition will reappear for Q_1 and Q_2.

B. Three-phase AC-DC Converter

The principle of operation of the three-phase ac-dc converter has been presented in [1] and is repeated here for ready reference. The proposed three-phase ac to dc converter (Fig. 1) consists of two main power conversion stages. The first stage is a three-phase ac to dc rectifier consisting of an input filter, a boost inductor; a three-phase diode rectifier, an active power factor correction stage, and a dc link filter capacitor. The second stage can be modeled as any type of load requiring a regulated or unregulated dc bus such as general purpose single-phase or three-phase inverters or dc-dc converters with high frequency isolation. The active waveshaping of the input current waveform is obtained through the use of the boost chopper components L_{ia}, Q_1, Q_2, D_7, D_8 ***and*** D_8 as shown in Fig. 1. The boost switches, Q_1, Q_2 are turned on at constant frequency. The duty cycles of Q_1, Q_2, are varied for load variation only and it is such that the input current is always discontinuous. During the 'on' period of the boost switches all three input ac phases become shorted through inductors L_{ia}, L_{ib}, L_{ic}, the six rectifier diodes and the active network. Consequently the three input currents I_{ia}, I_{ib} and I_{ic}, begin simultaneously to increase at a rate proportional to the instantaneous values of their respective phase voltages. Moreover the specific peak current values during each 'on' interval are proportional to the average values of their input phase voltages during the same 'on' interval. Since each of these voltage average values varies sinusoidally the input current peaks also vary sinusoidally. Moreover since the current pulses always begin at zero, it means that their average values also vary sinusoidally. Consequently all three input ac currents consist of the fundamental (60 Hz) component and a band of high frequency unwanted components centered around the switching frequency (f_s) of the boost switch. Since this frequency ***(f_s)*** can be in the order of several tens of kHz, filtering out of the unwanted input current harmonics becomes a relatively easy task. From Fig. 6 it is also seen that input power control (or output voltage regulation) can be achieved through pulse width modulation of the boost switch 'on' interval at constant frequency (f_s). Incidently f_s can be easily locked to the mains 60 Hz frequency to avoid 'beat frequency' effects in the input currents. Finally, under the operating conditions described here the 'displacement input power factor' cos ($\hat{O}_1$) before filtering is unity. Consequently, the overall input power factor (before filter -ing) becomes equal to the 'harmonic input power factor' and it is given by,

$$\text{Power Factor} = \left[\frac{\frac{I_{ia,1}}{\sqrt{2}}}{\sqrt{\sum_{n=1}^{\infty} \left(\frac{I_{ia,n}}{\sqrt{2}} \right)^2}} \right] \tag{1}$$

Where $I_{ia,n}{}^{th}$ is the Fourier component of the n^{th} harmonic component of current $I_{ia.}$ Cos $\hat{O}_1$ is the displacement factor. It is noted that the current harmonics associated with this power factor can be suppressed by a relatively small input capacitor (C_{ia}) and inductor ***(L_{il})*** because of their high frequencies. There are the overall input power factor after filtering (i.e. at the ac source) is very close to unity.

III. Input and Output Filter

The design of input and output filter components has been presented in detail in [l] and the relevant expressions are presented here. The value of the output filter capacitor is

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given by

$$C_d = \frac{I_{b2f_s(peak)} * 100 * (1-D)}{\sqrt{2} * (Ripple\ \%) * f_s * \omega * V_{an(peak)} * \sqrt{3}}$$

The values of the input filter components **are** given by [1]

$$\frac{X_{L_{i1,1}}}{X_{C_{ia,1}}} = \frac{1}{(f_s - 1)^2} \left[\frac{I_{ia\, f_s-1}}{I_{i1, f_s-1}} + 1 \right]$$

Evaluation of (6) shows that size of the filter components is a function of the switching frequency ***(f_s).*** The size of the filter components becomes smaller and smaller for higher switching frequency. Consequently all the harmonics of the input current ***(I_{il})*** becomes smaller and smaller and the input power factor is nearly unity.

Conclusions

It has been shown that application of the proposed active switching network (Fig. 1) in three-phase ac to dc boost converter yields zero switching losses while maintaining a unity input power factor- Active network capacitor, C_s, diodes D_7 and D_8 maintain a zero voltage during turn-off of $\boldsymbol{Q_1}$ and $\boldsymbol{Q_2}$ Capacitor, $\boldsymbol{C_s}$ discharges through the boost inductors of the circuits thus limiting the rate Of rise of current during turn-on. Moreover, the advantage of the proposed active network is that it can maintain a zero voltage switching over the entire range of the duty cycle of the operation. Consequently, boost stage can be used directly to control the dc bus voltage by varying the duty cycle at constant switching frequency. The resulting advantages include higher switching frequencies, and better efficiency. Finally the operation of the proposed active switching network has been verified experimentally on a prototype three-phase ac to dc converter.

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